State of Connecticut

State Geological and Natural History Survey

Bulletin No. 23

CENTRAL CONNECTICUT
IN THE
GEOLOGIC PAST

By

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BULLETINS

OF THE

State Geological and Natural History Survey of Connecticut.

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1. First Biennial Report of the Commissioners of the State Geological and Natural History Survey 1903-1904.

2. A Preliminary Report on the Protozoa of the Fresh Waters of Connecticut: by Herbert William Conn. (Out of print. To be obtained only in Vol. 1, including Bulletins 1-5.)

3. A Preliminary Report on the Hymeniales of Connecticut: by Edward Albert White.

4. The Clays and Clay Industries of Connecticut: by Gerald Francis Loughlin.

5. The Ustilagineæ, or Smuts, of Connecticut: by George Perkins Clinton.

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7. Preliminary Geological Map of Connecticut: by Herbert Ernest Gregory and Henry Hollister Robinson.

8. Bibliography of Connecticut Geology: by Herbert Ernest Gregory.

9. Second Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1905-1906.

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16. Guide to the Insects of Connecticut: prepared under the direction of Wilton Everett Britton. Part I. General Introduction: by Wilton Everett Britton. Part II. The Euplexoptera and Orthoptera of Connecticut: by Benjamin Hovey Walden.

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18. Triassic Fishes of Connecticut: by Charles Rochester Eastman.

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20. The Birds of Connecticut: by John Hall Sage and Louis Bennett Bishop, assisted by Walter Parks Bliss.

21. Fifth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1911-1912.

22. Guide to the Insects of Connecticut: prepared under the direction of Wilton Everett Britton. Part III. The Hymenoptera, or Wasp-like Insects, of Connecticut: by Henry Lorenz Viereck, with the collaboration of Alexander Dyer MacGillivray, Charles Thomas Brues, William Morton Wheeler, and Sievert Allen Rohwer. (In press.)

23. Central Connecticut in the Geologic Past: by Joseph Barrell.

24. Triassic Life of the Connecticut Valley: by Richard Swann Lull.

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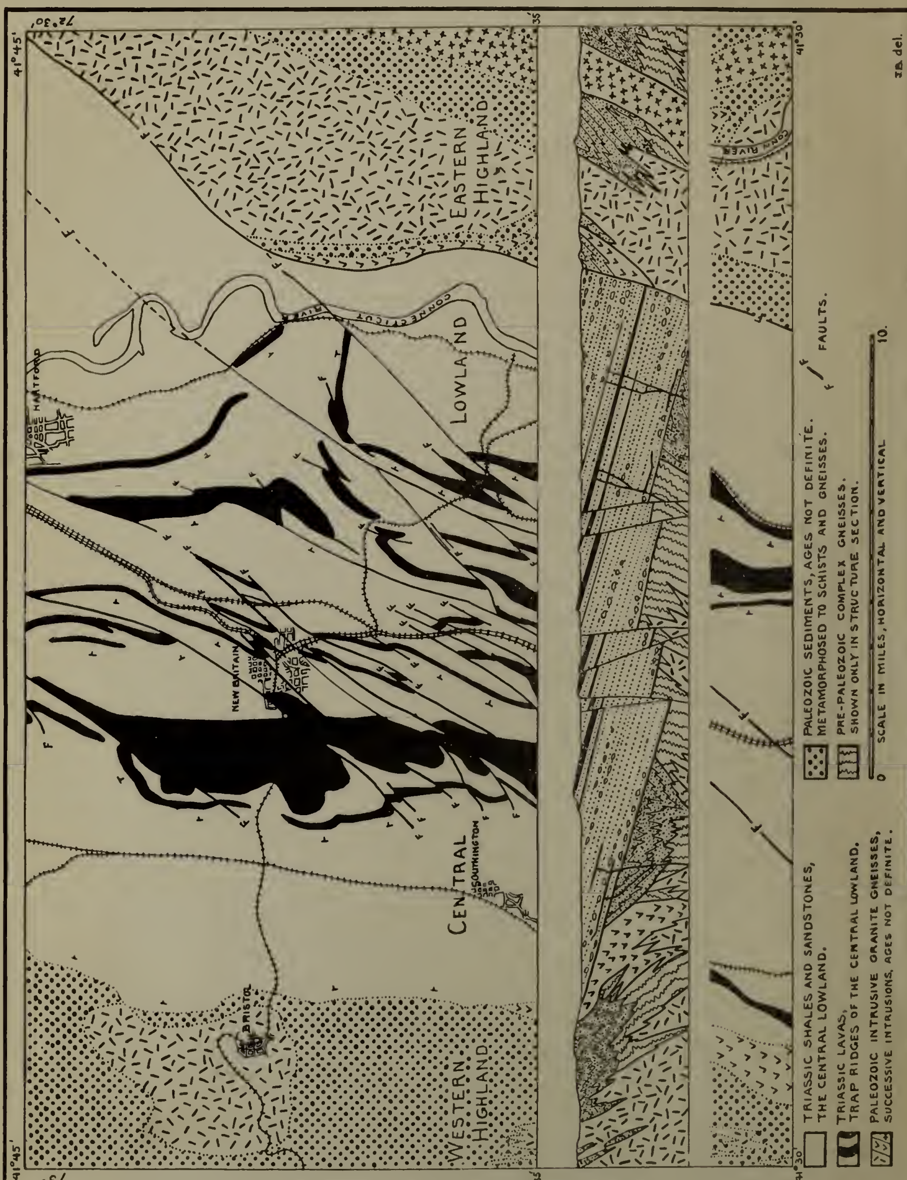

Figure I. GEOLOGIC MAP of CENTRAL CONNECTICUT
with
STRUCTURE SECTION on Lat. 41° 35′ N.

State of Connecticut
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CENTRAL CONNECTICUT

IN THE

GEOLOGIC PAST

By Joseph Barrell, E.M., Ph.D.
Professor of Structural Geology in Yale University

HARTFORD
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Central Connecticut in the Geologic Past.*

"The hills are shadows, and they flow
From form to form and nothing stands;
They melt like mists, the solid lands,
Like clouds they shape themselves and go."

Tennyson.

OUTLINE.

*This paper, in its original form, was read before the Wyoming Historical and Geological Society, April 28, 1911, and was published in their Proceedings and Collections, Vol. xii, pp. 25-54. It is now reprinted, with alterations and additions, by permission of the Wyoming Historical and Geological Society.

INTRODUCTION.

Plan of the Paper. — The great lesson taught by the study of the outer crust is that the earth-mother, like her children, has attained her present form through ceaseless change — change which marks the pulse of life — change which will cease only when her internal forces slumber, and her outer envelopes, the cloudy air and surf-bound ocean, no more are moving garments. The flowing landscapes of geologic time may be likened to a kinetoscopic panorama. The scenes transform from age to age, as from act to act; seas and plains and mountains of different types follow and replace each other through time, as the traveler sees them succeed each other in space. At times the drama quickens, and such rapid geologic action has marked the epochs since man has been a spectator on the earth.

Science demonstrates that mountains are transitory forms, but the eye of man through all his lifetime sees no change, and his reason is appalled at the thought of duration so vast that the millenniums of written history have not recorded the shifting of even one of the fleeting views whose blendings make the moving picture. The reason becomes convinced by argument, but drawings assist the imagination to rebuild on the visible rock foundations and eroded structures the shadowy outlines of the former landscapes which they imply. For such graphic study, Central Connecticut is here chosen. Statements of the present surface forms and geologic structures are given as a basis for the reconstruction by drawings of the forms and structures of the past. Having followed the evidence backward through the geologic ages to that period in which obscurity darkens the farther past, our vision is then turned forward and, while taking homeward flight to the present age, we behold the panorama of geologic time. But science not only reconstructs the past. It also asks the questions — why and whither. In order not wholly to omit an answer there is given therefore at the close of this study a brief conclusion on the meaning of the shifting scenes.

The limits of this paper and the great number of events which are reviewed prevent an extensive discussion of the local evidence, which may be found in large part in other publications.[1] The conclusions, however, depart from those previously expressed in a number of particulars, wherein studies of the field or theoretical considerations have led the present writer to other views. Since the subject deals with a graphic visualization of the past, it lends itself to popular treatment, and technical writing has therefore been avoided as much as possible even at the cost of some expansion in length. It should be added that the structure sections here presented are wholly new, and it is hoped that they and parts of the discussion may be not without interest to geological specialists.

Geologic History expressed by Structure Sections.— Geologic studies commonly center in a written description, and are illustrated by maps and structure sections which show the rock formations as they exist at the present time. In this article the form of presentation is reversed, and the later geologic history of central Connecticut is made to center about a succession of graphic portrayals, with written descriptions to precede and explain these views. A structure section passing east and west near Meriden and Middletown shows the rock formations as they would appear on the walls of a deep trench, and the surface outline shows the magnitude and relations of hills and valleys. Upon this structure section, as upon a wide canvas, the spectator may in imagination review the changes which have passed from age to age over this one portion of the earth.

The structure section of Present Geologic Time, as shown in Figures 1 and 2, is based upon the location of surface outcrops, and the information which these give to the geologist concerning the underground structure. But, except for the surface line, this, like other structure sections, is the product of the scientific imagination. The deeper the section is carried and the more complicated the geology, the more it must fail of accuracy,

[1] See especially Davis, W. M., The Triassic Formation of Connecticut. 18th Ann. Rpt. U. S. Geol. Surv., Part ii, pp. 9-192, 1898. Also, Rice, W. N., and Gregory, H. E., Manual of the Geology of Connecticut, Bull. No. 6, Conn. Geological and Natural History Survey, 1906. For geologic studies of the same formations in Massachusetts see especially Emerson, B. K., Holyoke Folio, No. 50, U. S. Geol. Surv., 1898.

though its value may still be great in graphically explaining the geologic history of the region.

The surface of the earth, which alone is open to observation, is, however, a changing surface, the product of erosion, separating that portion of the rocks which is invisible because destroyed, from that other portion which is invisible because not yet brought to the scene of destruction. From the study of this soil-clad surface which intersects the original structure of the rocks, the vanished portion above our heads may be as legitimately portrayed, by the same methods of reasoning and with the same degree of accuracy, as the invisible structures below our feet. The structure may then be progressively simplified by taking away the effects of successive crustal movements and thereby graphically show the structural evolution.

The corresponding landscape may be restored for each stage by invoking the principles which underlie erosion and deposition and applying these to interpret the relations between the present and the past. It has been noted that the accuracy of details in the structure section becomes less the farther they are from the controlling surface of observation, and, in a similar manner, the accuracy of the delineation of the ancient surface of erosion becomes less the farther it is removed from relationship with the present landscape. Limits are therefore reached in geologic time as well as in hidden depth, beyond which inference weakens and portrayal cannot go.

The method has its value on the one hand in overcoming the confusion of words and in visualizing impressively change following change in the protean earth. It shows with some degree of geologic precision the chronologic mile-posts of the flowing landscape. But the limitation of scale of the drawings precludes the representation of details, such as met the eyes of the changing denizens of each age. The restoration of these bygone forms of life and the scenes among which they lived requires the imagination and the pencil of the geologic artist.[1]

[1] See Bulletin No. 24 of the Connecticut Geological and Natural History Survey, Triassic Life of the Connecticut Valley, by Richard Swann Lull, Professor of Vertebrate Paleontology in Yale University. This bulletin treats in detail the life of Triassic times as drawn in part from knowledge of the bones, but especially from the wonderfully rich and unique footprint record of the Triassic rocks of Connecticut and Massachusetts.

The graphic method has the disadvantage, on the other hand, of requiring the definite expression of detail, where in the nature of the problem a knowledge of detail is more or less absent; but this defect, inherent in drawings, is seen to be unimportant if the reader follows the evidence on which they are based and uses them for the purpose of visualizing general conclusions.

The conventional structure sections show neither the landscape of the background nor the clouds above, but for the present purpose these may effectively be added. The atmosphere and its clouds belong to the earth. In wind and rain they play their parts in the geologic drama. Climate is expressed in the present to some extent by cloud forms, and ancient climates are recorded in the crust by the character of the contemporaneous erosion and sedimentation, — the work of former sun and frost, of rain and wind, of moving ice and water. Furthermore, each type of cloud has a tendency toward a certain size and elevation, and gives a rude gigantic scale against which may be measured the mountain heights. Observations at the Blue Hill Observatory, for example, showed that the cumulus, or summer day clouds, in summer have their flat bases at an average elevation of 4,900 feet above the land surface, in winter at an elevation of 4,600 feet. Their rounded, tumultuous summits rise to an average of 1,500 feet above their bases.[1] The heights as found in other countries are not markedly different, but the average height increases about 1,400 feet from morning to noon, and from day to day may depart from the mean for the hour of the day within somewhat similar limits. The flat base of the cumulus may be regarded, therefore, as usually ranging from three-quarters of a mile to a mile and a quarter above the surface of the plains.

The Forces of Geologic Change. — Sun and frost, air and rain, slowly cause the rocks to crumble, and with the aid of plants convert them into soil. But the soil creeps down the slopes; it is partly dissolved by water and partly blown away by wind. Rivulets carry this land waste to rivers. Rivers grind their channels deeper by sweeping along the bottoms the pebbles and the sands. When the rivers have reached their lowest level they lay down their burden by spreading it over lowlands or giv-

[1] Clayton, H. H., and Ferguson, S. P., Measurements of Cloud Heights and Velocities. Annals of Astronomical Observatory of Harvard College, Vol. xxx, Part iii, 1892.

ing it to the sea. Layer after layer is buried beneath ever younger layers, and, as sedimentary strata, with their record told by fossils, the whole in after ages is reconverted into rock.

But it follows that the uplands are being degraded always toward the level of the sea; the marginal seas and basins are likewise being filled. But in the lofty mountains the forces which destroy the rocks work with greatest power; the cliffs are broken down to talus and the slopes subside more slowly into soil-mantled hills. The hills in the course of ages flatten down, so that the ultimate landscape has valleys which are broad and ill-defined, separated by low and gently sloping hills, the whole a surface of erosion which is known as a peneplain. Thus after crustal uplift the landscape passes through an erosion cycle from young and rugged mountains, to maturity marked by gentler mountain slopes, thence to prolonged old age. The work of erosion is then insignificant save for the ceaseless fretting of the ocean on its shores.

The length of the erosion cycle is, however, dependent upon the durability of the rocks. Shales are soft and limestones soluble. These will melt away in a fraction of the time needed to destroy equal volumes of quartzite or granite-gneiss. An erosion cycle in such soft rocks as the shales of central Connecticut will in consequence pass into old age, while the erosion cycle begun at the same time on the harder masses of crystalline rocks which exist to the east and west is still in the stage of youth. Erosion cycles of different beginnings, different lengths, and different degrees of progress toward completion will therefore be coexistent.

But what are the causes which rejuvenate erosion and continue geologic change? The crust, through the action of vertical or horizontal forces, periodically becomes broadly warped and bowed; or it breaks into blocks, or is folded into mountain ranges. Molten masses may invade the crust from the depths below or pour out upon its surface. Thus the renewal of erosion is dependent upon diastrophism and vulcanism, under which terms are included all processes emanating from the inner earth.

But, if the uplifts have been so great that erosion finally cuts down to levels which were once miles below the surface, the rocks then exposed are found to be contorted and mashed, crystal-

lized and hardened from the pressure and heat of the depths. In this way limy sediments of the sea, after deep burial and subjection to mountain-making forces, become crystallized to marbles. Muds, first hardened into shales, are finally transformed into sparkling mica schists. Sandstones pass into lustrous quartzites. Granites are mashed into banded rocks known as gneisses. All these crystallized and hardened forms are classified as metamorphic rocks. They are the foundation whose broad exposure at the surface testifies to the destruction of ancient mountain ranges. Their resistance prolongs the erosion cycles which upon each renewed uplift begin their re-destruction. Let them be planed down to the level of the sea and then uplifted. The upwarped peneplain will endure for a time, largely undestroyed, existing as a plateau trenched by narrow valleys even after the softer rocks have been again eroded to another low-lying plain. Or let submergence occur. The rivers and the sea will then lay down layers of sand and mud across the level floor of contorted and eroded mountain structures. The surface of the ancient land is now a surface of unconformity, and the latter as a record of an erosion cycle has become a part of the geologic story, but the record is concealed unless new forces warp or fold the rocks and again subject them to erosion.

The Measure of Geologic Time. — Man measures his life by a few scores of years, but the years of the earth are measured by many millions, an abyss of time so vast in comparison that the mind cannot fathom it save by the use of analogy. Let a year be represented by a foot; the average length of human life is measured then by the breadth of a dwelling house, and human history is limited approximately to a mile; but the duration of geologic time is measured in terms of the circumference of the globe.

The length of geologic ages cannot be stated accurately in years, but the rather conservative estimates of J. D. Dana are given in the annexed table of geologic time. Certain lines of evidence suggest that the geologic ages may be many times longer, but no reliable estimate yields a lesser duration than that given long since by Dana. The ratios of the relative duration of the eras are presumably more reliable than the estimates of the lengths in years. It is seen that each preceding era of the last

four is longer than the sum of all succeeding eras, but as to the duration of the first two eras not even their ratio to the later times is known. In the region selected for the present study the history can be well deciphered as far back as the beginning of the Mesozoic era, and it will be seen that many events which have transformed the face of nature have been crowded into that time. Yet it is probably not more than the last fourth of that geologic time which has elapsed since the beginning, in the Cambrian, of the fossil record of living forms; nor more than a tenth of the entire history of the world. The length of the geologic periods is measured by the work of erosion and deposition; and the changes which have passed over central Connecticut from period to period, as expressed in the accompanying drawings, enable the reader to form some estimate for himself of their relative duration. In most cases it is seen that each preceding change involves a greater transformation and implies a longer lapse of time than those which follow, corresponding thus to the estimates of the table. But knowledge becomes vague in proportion as the evidence has been obliterated in the recording of later events, and the student of geologic time looking over the illimitable past sees the vista recede like a mountainous landscape. Beyond the near-by foothills range after range breaks the view, each rising higher, the scale of magnitude continually increasing; but the eye gradually loses all detail of form. Beyond the blue horizon's rim the reason knows still other mountains lie.

TABLE OF GEOLOGIC TIME

Minimum estimate of length in years	Eras	Periods	Ages
30,000	Psychozoic	Human	Age of Man
3,000,000	Cenozoic	Quaternary or Glacial Tertiary	Age of Mammals
9,000,000	Mesozoic	Cretaceous Comanche Jurassic Triassic	Age of Reptiles
36,000,000	Paleozoic	Permian Pennsylvanian Mississippian	Age of Amphibians or Carboniferous Age
		Devonian Silurian	Age of Fishes
		Ordovician Cambrian	Age of Higher Invertebrates
?	Proterozoic	Keweenawan Animikian or Upper Huronian Middle Huronian Lower Huronian	Age of Primitive Invertebrates (Fossils almost unknown)
?	Archeozoic [1]	Keewatin Coutchiching ?	Age of Protozoa (Fossils wholly unknown)

DESCRIPTION OF CENTRAL CONNECTICUT.

A Part of the Appalachian Province. — The geologic province of the Appalachian mountain system stretches from Newfoundland to Georgia and in width it reaches from the Atlantic coastal plains to the plains of the Central States. It is divided into many belts, which form sub-provinces, each with its own geologic record, each telling better than another some particular geologic story. The history of each region is in part local, in part general. A description, therefore, of the geologic past of central Connecticut since the Paleozoic gives a general view of events similar to those which have passed over all that belt of the Appalachian

[1] The Archeozoic and lower Proterozoic make up together the complex of basal rocks often called the Archean.

system which stretches through Massachusetts, Connecticut, New Jersey, and southeastern Pennsylvania to central North Carolina. To a lesser degree the history has corresponding stages in those belts of the Appalachians to the east and west. The local description, besides giving details of local interest, serves, by concentrating the attention, to bring out sharply the magnitude of the changes which mark the passage of geologic time. It is thought, therefore, that such a discussion may serve for more than local interests.

The Surface Features. — The surface of the land is the product of erosion. The erosion of the portions above sea level during each period has furthermore been carried to varying degrees of completion. The result has been to divide Connecticut into three geographic provinces, the Central Lowland, and the Eastern and Western Highlands. The Central Lowland trends nearly north and south across the central part of the State and extends northward across Massachusetts. On the northern boundary of Connecticut it has a breadth of twenty miles, but narrows southward to about eight miles at the latitude of New Haven. It constitutes throughout most of its length the broad valley of the Connecticut River, but the latter abandons the Lowland at Middletown and has carved from that point a gorge diagonally across the Eastern Highland to Long Island Sound. The southern end of the Central Lowland is consequently drained by several small rivers which flow into New Haven harbor. With the exception of the narrow belts of marble which occur in the western part of the State, the Triassic shales and sandstones which underlie the Lowland are the rocks least resistant to decay and erosion, and have, therefore, been worn low, rapidly from the geologic standpoint. The Eastern and Western Highlands are, on the contrary, with the exception of the small Pomperaug Valley lying west of the map, Figure 1, underlain wholly by metamorphic rocks; these are crystallized sediments or mashed and recrystallized igneous rocks. With the exception of the marble belts the metamorphic rocks are hard and insoluble and therefore slow to decay into soil. But this means slow erosion, as discussed under a previous heading, save where the stream currents, carving with the sand and gravel of their beds, wear out narrow valleys. Thus it is perceived that

the geologic structure is the fundamental factor which controls the nature of the surface.

The Central Lowland is in its larger aspect a plain, but in detail it is seen to consist largely of low hills with flowing outline. The rivers meander through the Lowland in broad valleys but with well-defined channels. Prominent but interrupted ridges of trap rock run the length of the Lowland and rise several hundred feet above the general level. The principal streams are less than a hundred feet above the sea, but the rolling surface of the Lowland lies mostly from 100 to 400 feet higher, the northern parts in Connecticut averaging about 100 feet higher than the southern. The gentle slopes and deep soil are suited to agriculture; numerous small cities and several larger ones have developed and communication is easy in all directions.

The Lowland plain bevels the strata of the rocks beneath and is therefore a plain of erosion. But, even if the present narrow river valleys be in imagination refilled with the rock which the streams have excavated, the Lowland surface will be seen to be not level, but diversified by low hills 100 to 200 feet in height. It is therefore not a plain but a peneplain; that is, almost a plain. The general uniformity of level at an elevation which in central Connecticut averages about 200 feet, indicates, furthermore, that the peneplain was developed by subaerial erosion when the land stood about 200 feet lower than at present. A more recent uplift has permitted the streams to cut to a lower level, and erosion has begun to destroy the peneplain which formerly it brought into existence, by beginning to create a new one at the present level of the rivers.

The Eastern and Western Highlands are in their larger aspects plateaus, and in regions removed from the principal rivers, as at Litchfield, this relative flatness of the upper surface is conspicuous, the local relief being no greater than in the Central Lowland, though the average elevation may be more than a thousand feet above the sea. Over most of the highland area, however, the rivers and their tributaries have sunk into the upland, eroding narrow valleys of considerable grade, dissecting the plateau into a greater or less ruggedness, and making communication across the drainage systems more difficult than in the Lowland. If the valleys be filled in imagination with the rock which the rivers have removed from them, the plateau character

of the Highlands becomes apparent. But it is not a level plateau; on the northern boundary line of Connecticut it attains an elevation of about 1700 feet above the sea in the west and descends to an elevation of about 600 feet at the eastern limit of the State. From this elevation on the north the plateau slopes southward, and the place where it reaches sea level determines the Connecticut shore line of Long Island Sound. At the southern limit the dissected Highlands therefore grade into an undissected lowland, albeit one of rocky character. The result is that along the shore Lowland and Highlands lose their distinction in elevation; and the only railroad which runs across the State independently of both rock structure and river valleys is the line of the New York, New Haven and Hartford Railroad which runs along the shore from the New York to the Rhode Island boundary. On the Highlands the soil is in general thinner and more stony than on the Lowland, and agriculture meets with less reward.

The Highland surface, like that of the Lowland, truncates the rock structure. It is, therefore, like the latter, the product of erosion, but during an earlier geologic period, when this plateau surface lay near the level of the sea, and erosion continued to sap the slopes of all hills which rose above its surface, but could not carve the rocks below. The hills gradually melted down until they possessed but a remnant of their former height. The valleys became broad and open. A peneplain extended far and wide, interrupted by a few remaining mountain knots. Then after a long interval a broad swelling uplift of the land created a lower sea level — a lower base-level toward which the rivers began to etch their channels — and the Highlands began to be destroyed.

The plateau surface has commonly been considered as entirely the product of one cycle of river erosion, but upwarped and tilted in several stages until it reached its present altitude. The opinion is held by many geologists that before the uplift the sea had planed the surface as far north as Meriden and Middletown, laying down a thin mantle of coastal plain deposits which since the uplift have been eroded from the surface as far south as Long Island.

Studies by the writer have led him, however, to a somewhat different view,[1] the detailed evidence for which has not as yet

[1] Barrell, J., Piedmont Terraces of the Northern Appalachians and their Mode of Origin: Post-Jurassic History of the Northern Appalachians. Bull. Geological Soc. Am., vol. 24, pp. 688-691, 1913.

been published. Careful study shows the Highland surface not to consist of one irregular sloping plain, with low hills rising above and deep valleys cut below. On the contrary, if the valleys be filled in imagination and the ravages of erosion repaired until the country is level with the higher hill tops, it will be found that the upland level resembles an irregular flight of giant stairs. The rises are commonly about 200 feet in height, but weathered down to very gentle slopes. The treads average from five to ten miles in breadth and are more nearly level than is the general slope of the upland surface.

Over much of the country the entire original surface has been destroyed and leaves no clue to its original nature, but on the Western Highland it may still be restored. Near Naugatuck many level-topped ridges rise to elevations of from 700 to 740 feet. Above them on the north is a belt of scattered higher hills which reach most extensive development in the town of Prospect at elevations of about 920 feet. In the region of Litchfield the next level shows in many flat hill-tops at 1100 to 1140 feet. Rising above these on the north is a wide belt of rolling hill-tops in the town of Goshen which reach from 1340 to 1380 feet in height, and farther to the north are scattered higher hills which represent still older and higher levels.

The interpretation which this stair-like or terrace character of the restored Highland surface seems to demand is, that, after a peneplain had been developed, the sea planed inland along the entire Atlantic shore, completely across the state of Connecticut and over most of Massachusetts. During this invasion the sea may have partly cut the benches, but most of the terraces were doubtless cut as sea cliffs during oscillations of the shore line which accompanied emergence of the land. The cliffs cut by the successive inroads of the sea resulted in a surface partly of terrestrial, partly of marine erosion,— a sea-benched peneplain, of which the lower and seaward terraces are much younger than the higher and landward ones. But the lower terraces, those below 700 feet in elvation, were imperfectly developed because of more rapid oscillations and a greater dominance of river trenching. The higher terraces have been so largely destroyed that the details of the landscape are due wholly to later subaerial erosion. It is in the original control of the higher levels that the

ancient sea terraces become of importance. Little suggestion of them, however, can be seen by a casual study of the landscape. It is rather a comprehensive study of topographic maps which supplies the evidence, but a final conclusion on this subject must await a detailed publication.

The Rock Structure. — The erosion surface gives the data for deciphering one side of geologic history, that of the surface activities; the rock structure gives another side of this history, that connected with the forming and transforming of the rocks.

The structure section shown in Figure 1 shows the attitude and nature of the rock formations, the oldest being united in one group — the pre-Paleozoic complex gneisses. Back of the Paleozoic ages lies a tangled record, which speaks, however, of eras of mountain-making, erosion, and sedimentation, followed at last by a manifestation of mountain-making forces on a prodigious scale. The sediments were crystallized, mashed, and injected with sheets and masses of molten rock, thus developing the pre-Paleozoic complex gneisses, the result of internal forces so vast as to remake the crust and everywhere hide in obscurity the earliest history of the earth. This "Basement Complex" does not rise to the surface on the line of the structure section, its nearest outcrops being in the northwestern portion of the State.

The second group of rocks shown in the drawings comprises the Paleozoic sediments. During the greater part of that era most of the area of Connecticut was, as now, a part of the land, but then, in marked contrast with present conditions, it stood on the eastern side of an inland sea. Long Island Sound was not yet in existence, and the Appalachian continent, now in large part submerged, extended to the south. The mountain system was furthermore subjected more than once to movements of folding and uplift. The Paleozoic sediments therefore represent only certain periods when the land stood lowest and the sea held widest sway. But not all of the sediments are positively marine, some of them may have been formed as delta deposits skirting uplands and built out against a western shallow sea. Only portions of the Paleozoic sediments have been preserved, that is, the parts which were folded down rather than thrust up. The folding, mashing, and crystallization to which these sediments were subjected in mountain-making movements of the Paleozoic, especially near

its close, were so great in the Connecticut area as to transform them completely into crystalline schists and gneisses. All fossils which they once may have contained have been obliterated, and the age of the sediments, further than that they belong to the Paleozoic, is not positively known.

The third group of formations comprises the intrusive igneous rocks of Paleozoic age. They are mostly granite-gneisses, forced at repeated intervals into the older rocks as molten masses of great volume, solidifying into granites, later crushed into banded rocks known as gneisses. Their invasions record times of revolution, of uplift and mountain-making, even as the sediments into which they were forced record times of quiet and local subsidence. The intrusive rocks probably belong mostly to the closing periods of the Paleozoic, when the ancient order of lands and seas and the life inhabiting them was being broken up, and the world stage was being reset for the drama of the Age of Reptiles. But, since the sediments are not precisely dated, neither can the age of the granite-gneisses be definitely known. Farther west, in New York State, seas prevailed much of the time until near the close of the Paleozoic, and the unmetamorphosed strata record with fulness the progress of life and the sequence of the ages. But near the western border of New England many formations disappear, others change their sedimentary character, metamorphism masks their original nature, and before the Central Lowland is reached they pass into a tangle of metamorphic and igneous rocks, a second Basement Complex, only less profoundly changed than the pre-Paleozoic Complex below. Indeed, until within recent years no separation was made between them, and the greater part of Connecticut, with the rest of New England, was regarded as made of rocks of Archean age. Although the original nature of the sediments is so greatly blurred, the metamorphism and igneous intrusion clearly record a history still more impressive to the imagination; for they are the basement structures of an ancient range of mountains, the Paleozoic Alps of New England, a generation of mountains long since vanished, but whose rugged slopes and majestic heights the mind of man has learned to build anew.

The fourth group of rocks shown on the structure sections is that of the Triassic sediments and lavas. The sediments are

mostly red or brown shales and sandstones with, in certain localities, many conglomerate beds. Intrusions of trap were forced into these sediments as molten sheets, and at three separate times great floods of lava spread far and wide over the surface. These were poured out while the Triassic muds and sands were accumulating and subsiding, and each in turn became buried beneath the later beds of the formation. Uplift of the neighboring regions and subsidence over the region of accumulation permitted erosion and sedimentation to proceed until a maximum thickness of certainly more than two miles, very possibly as much as three miles, had accumulated. The sediments and the lavas were laid down in approximately horizontal sheets, but they now exhibit a regional dip to the east which averages from fifteen to twenty degrees. Erosion has planed across these inclined strata, exposing them to view from top to bottom. The trap flows consist of harder rock and have not been worn so low as the soft rocks which underlie the valley floor. The outcrops of the lavas, however, are broken and offset and repeated, indicating that the Triassic formation has been shattered into great crust blocks which have slipped on fault planes hundreds or even thousands of feet with respect to each other. The original position of the sediments has therefore been modified by both tilting and faulting as shown on the structure section. The floor upon which the Triassic land waste began to be laid down has again become exposed as the eastern slope of the Western Highland. It is a fairly plane surface eroded across various metamorphic rocks, and indicates a great lapse of time following the elevation of the late Paleozoic mountains, before the beginning of the Triassic sedimentation.

The life record as shown by the abundant footprints and the rare fossil bones belongs to the upper Triassic and may extend into the Jurassic period.

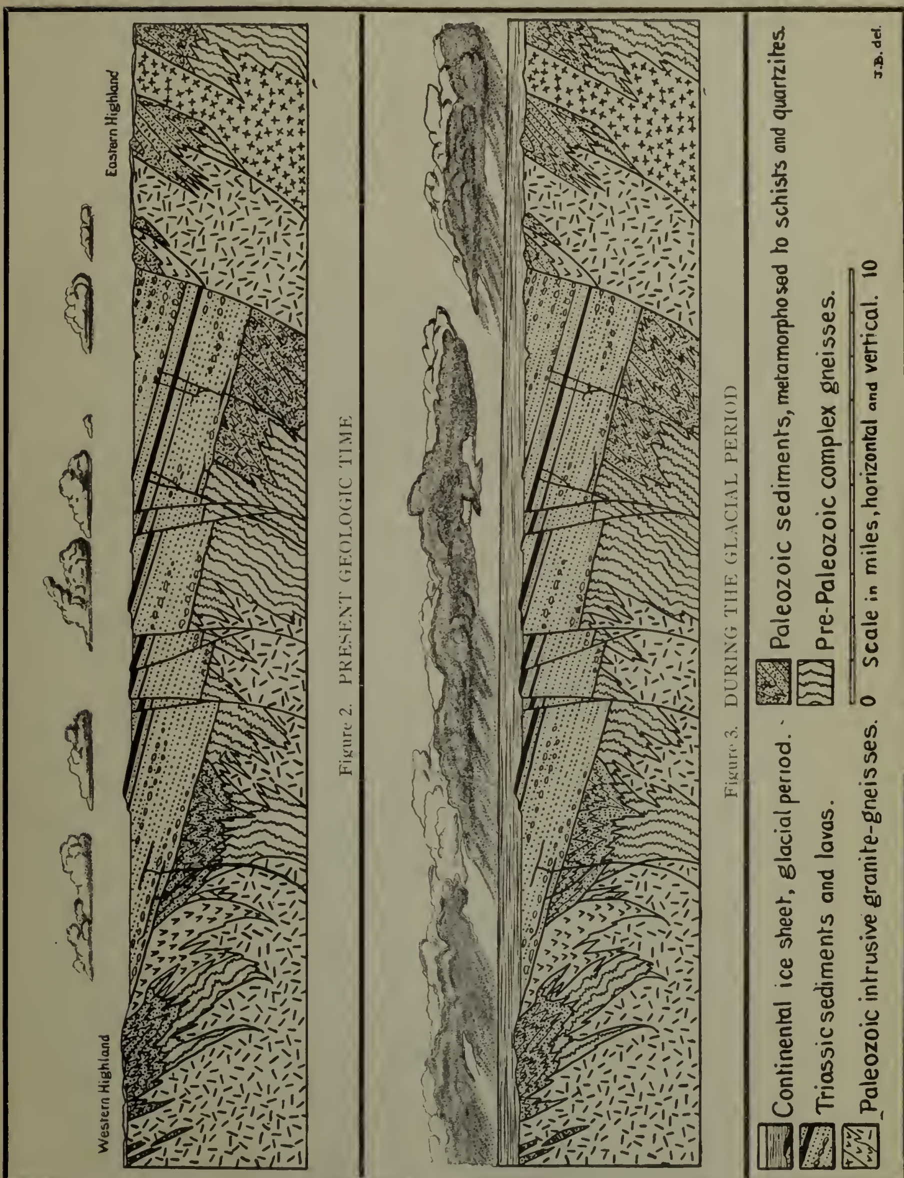
Later than the Triassic the only deposits in Connecticut consist of the thin mantle of Glacial drift, and surface gravel, sand, and clay, which marks the presence and the retreat of the continental ice sheet of the geologically recent Quaternary period, the age of ice. After this general review of the geology of central Connecticut, attention may be turned to the structure sections

which represent the successive geologic events and to the evidence upon which each is based.

STRUCTURE SECTIONS OF SUCCESSIVE GEOLOGIC PERIODS.

The Present Geologic Time, Figure 2. — The section shows the relatively slight relief of the valley ridges and the Highlands above the Central Lowland, as compared to the former reliefs implied by the eroded structures. A new cycle of erosion has begun but has not yet made much progress toward completion, as shown by the narrowness of the alluvial flood plains, the hilly character of the Lowland on a small scale, and the steep slopes of the valley walls. Uplift has therefore been geologically recent, but has been of a broad and uniform nature, since the next older base-level of erosion represented by the peneplain of the Central Lowland is still approximately level though slighly higher in the north. Its elevation on the line of the structure section is about 200 feet and this marks the amount of uplift. The present cycle of erosion, however, although but slightly advanced, has been in progress since at least the middle of the Quaternary period, as the river valleys are mantled with Glacial till and floored with outwash gravels, showing that they were eroded before the last invasion of Glacial ice. The progress of the cycle toward completion is, therefore, a measure of the relative length of a part or all of the interglacial stages of the Quaternary period, rather than a product of post-Quaternary time. But the uplift has been so small and the erosion of the rock last raised above sea level is so little advanced that the results cannot be given expression upon the structure section. The importance of noting its occurrence lies in pointing out the relative insignificance of recent erosion, and in emphasizing the fact that all the features shown in the drawing are the impress of earlier geological periods, not of that in which we live.

Connecticut during the Glacial Period, Figure 3. — The continental ice sheet reached as far south as Long Island, and buried all the hills of Connecticut, as well as the Catskill, Green, and White Mountains. From various lines of evidence, its thickness over the Central Lowland on this section line, when at its maximum, may be estimated as approximately a half-mile. It was an



STRUCTURE SECTIONS of CENTRAL CONNECTICUT

Lat. 41° 35′ N.

unbroken desert of ice mantling the northern half of the continent, similar to the present ice caps of Greenland and Antarctica, and attaining a thickness of at least two miles in its central portions; a desert whose icy floor was in slow but perpetual motion toward its margin, while its surface snows, like the dusts of tropical deserts, were hurtled outward more rapidly than the solid ice below by the freezing winds which at short intervals blew from the interior. The ice removed the original soil and ground off a certain amount of rock, but did not remodel the landscape; it left the landscape in all its larger features essentially as it found it, a surface shaped by subaerial decay and running water. Upon the final retreat, however, a disordered mantle of glacial waste was left upon the rock floor. The hollows were marked by lakes and swamps; the river valleys were choked with sand and gravel deposited by the streams flowing from the receding glacial margin. Such features cannot be expressed upon the section but constitute the evidence from which the appearance of the ice cap is restored.

The Close of the Tertiary Period, Figure 4. — During the Tertiary period several movements of regional uplift of the Appalachian province took place, and at each halt the rivers carved down to near the new and, with respect to the rocks, the lower level of the sea; their tributaries sapped the hills and a new cycle of erosion with respect to a new base-level became initiated. In the latest Tertiary the land again stood still for a considerable time, and the peneplain of the Central Lowland became developed at sea level. The time, however, was too short for the harder rocks of the Highlands to suffer much destruction, and the difference in level between the general highland surface and the lowland measures the amount of the several Tertiary movements. At about the close of the Tertiary the temporary crustal quiescence was destroyed. A marked uplift of the lands, especially in higher latitudes, preceded the gathering of the ice sheets and characterized the earlier portion of the Glacial period. It occurred in several stages and was marked by oscillatory reversals, but the aggregate effect was to initiate a new cycle of erosion, during which Chesapeake and Delaware Bays and Long Island Sound were carved as river valleys in the soft deposits of the Coastal Plain, and gorges and narrow valleys were cut by the larger

streams farther inland. The structure section shows the gorge of the Connecticut River trenched in the peneplain of the Central Lowland. A subsidence which began in the latter part of the Glacial period has, however, brought the Central Lowland part way back toward its original level. This lower attitude of the lands, as compared to the elevation attained in the latter part of the Tertiary and early part of the Glacial period, has resulted in the development of Long Island Sound and the partial silting up of the channel of the Connecticut River.

In the Cretaceous Period, Figure 5.— During the Jurassic period erosion had progressed over the Appalachian region until, along the region which is now the coastal plain from Connecticut southwestward, wherever the evidence has been preserved, the country had been reduced to a peneplain. Hills several hundred feet in height still diversified its surface, however, and, farther inland, mountain groups doubtless continued to exist. Then, at the beginning of the Comanche period a new movement was manifested. Upwarping became pronounced along the entire Appalachian system, but the upward movement was restricted to that northwestern belt where the present highest elevations are still found, extending from the White Mountains to the Southern Appalachians. Southeast of the Mountains, on the contrary, a downwarping took place, carrying this belt below base-level, and obscuring the fact that in earlier periods this too was a part of the mountain system. These movements corresponded to a warping or tilting about a horizontal hinge-line or axis which followed in a general way the line of the present great Atlantic seaboard cities, Boston, New York, Philadelphia, Baltimore, Washington, and Richmond. Northwest of this line the uplift increased with distance from the hinge-line. On the southeast, subsidence increased with the distance. Erosion was reawakened in the uplifted region and numerous rivers carried the land waste southeastward to that region which was sinking. The rivers here could no longer erode but began to build by depositing their sediment. For a time this was more than enough in volume to compensate for the subsidence, so the sea waters were kept back and a delta plain was built out along the entire Atlantic shore. The fresh-water deposits of what is known as the Potomac formation were thus laid down in unconformable relation upon the

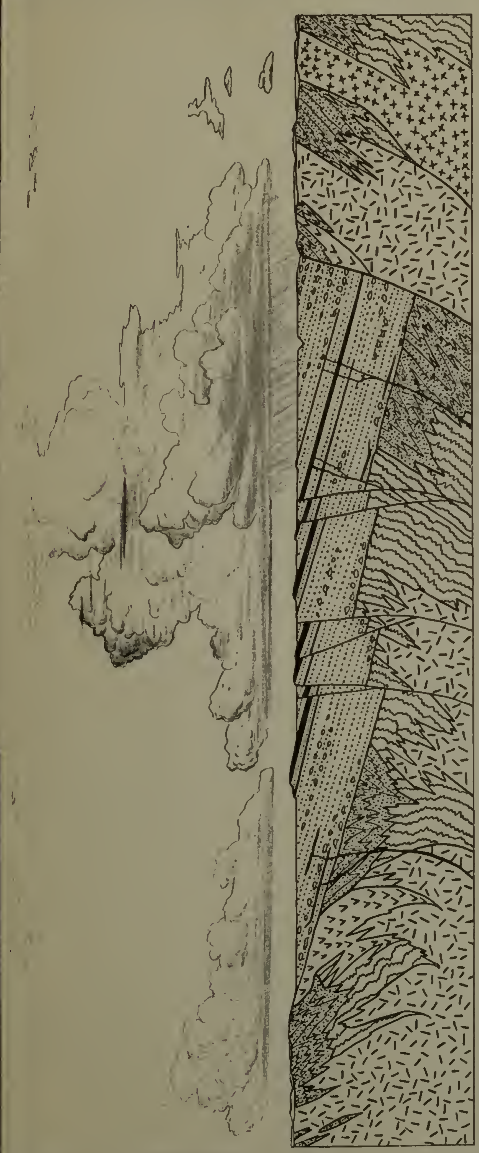


Figure 4. CLOSE OF THE TERTIARY PERIOD

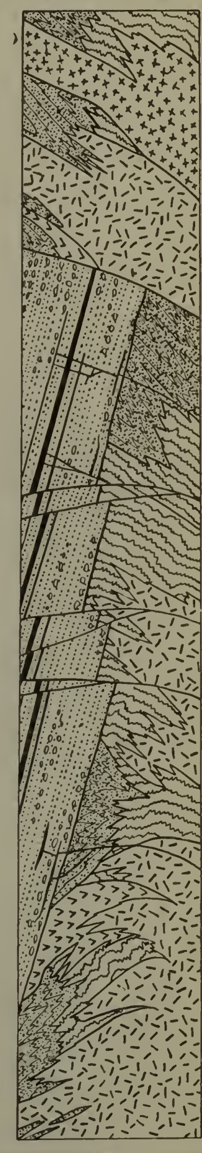


Figure 5. IN THE CRETACEOUS PERIOD

Triassic sediments and lavas.

Paleozoic sediments.

Paleozoic intrusive granite-gneisses.

Pre-Paleozoic complex gneisses.

0. Scale in miles, horizontal and vertical. 10.

STRUCTURE SECTIONS of CENTRAL CONNECTICUT

older rock structures. These sediments thicken to the southeast, and their nature and that of the floor which they rest upon give the evidence on which the preceding statements have been based.[1]

But by the beginning of the Cretaceous period the inland upwarping had slackened, while the seaward downwarping still progressed. The rivers were therefore no longer supplied with sufficient sediment to maintain their delta plains above the surface of the sea. Erosion continued to degrade the mountains on the northwest and the sea began to plane far inland from the southeast.

A sinking land, especially one in which sinking accompanies a seaward tilting, permits the waves to roll inland with but little diminished force and to erode vigorously at the shore. The residual hills left by river erosion, projecting as headlands and islands, are planed away, and the peneplain developed by subaerial erosion becomes converted into a plain of marine denudation. As the Cretaceous strand-line, owing to these actions, advanced farther inland, submergence at the same time brought deeper water over the more seaward portions and deposition of marine sediments began.

Davis was the first of geologists to point out the evidence, shown by the river courses, that the sea probably advanced as far as central Connecticut, or about to the line of the structure section shown in this paper; but, as stated previously, the writer holds that there is evidence of another kind that the Cretaceous sea at its maximum extended even farther, spreading in fact to the foot of the White and Green Mountains, and covering what are now the high plateaus south and east of the mountains. During the rest of the Cretaceous and perhaps well into the Tertiary Connecticut remained a coastal plain. Slight oscillatory vertical movements of the sea or land caused wide movements of the strand-line, and the portion north of Middletown emerged permanently from the waters long before the southern portion of the State. The nature of its surface then resembled the present surface of southern New Jersey and the eastern shore of Maryland; that is, it consisted of low sandy plains shelving out into a shallow sea. From the emerged portion the soft sediments were soon washed

[1] The writer has discussed this subject more fully on pages 405-414, Vol. 23, Bull. Geological Society of America, 1912.

away, and erosion began weakly to etch once more into the low floor of older rocks which was again exposed.

At last, during the later Tertiary period, a movement of more pronounced emergence began; the sea retreated, perhaps with geologic rapidity, to the line of the present shore or even farther. The rivers extended their lower courses across the low-lying and newly exposed mantle of coastal plain sediments, flowing down the gentle slopes in direct lines toward the sea. The unconsolidated sands and clays were soon removed, but their presence had served to permit the establishment of valleys diagonal to the older structure. The rivers flowed in superimposed courses not in harmony with the belts of softer rocks. Those of sufficient erosive power, like the Connecticut below Middletown, have maintained to the present their initial courses, cutting gorges across the hard rocks which lay across their beds. Smaller rivers, however, possess less erosive power, and have been deflected into new channels following the outcrops of the less resistant rocks. Upwarping and progressive tilting in several stages have continued, till now the old base-level of Cretaceous times passes above that terraced and dissected surface of ancient rocks which constitutes the Eastern and Western Highlands.

According to this outline of Jurassic and Cretaceous history, the structure section shown in Figure 5 applies to the time when the shore was in the vicinity of central Connecticut. It shows the time when the earlier generation of Appalachians had been wholly effaced from Connecticut, and the present generation of ridges and plateau remnants had not yet been born. Erosion had completely severed the continuity of the landscapes of the Cenozoic with the landscapes of the Mesozoic.

But the hills carved from that uplifted peneplain still rise bold and high in the Age of Man. They show that the time which has elapsed since they were uplifted is far shorter than the time which was required for the destruction of the previous order of mountains. They give by contrast a vista of the vast duration of the periods of the more remote past.

The Block Mountains of the Early Jurassic, Figure 6. — The Triassic sediments of the Connecticut Valley and other areas in eastern North America show by their fossils that they were deposited in late Triassic time. Their deposition was closed by a

breaking of the crust into great blocks which slipped past each other and rolled over so that all sloped to the east. The New Jersey area of Triassic rocks is also faulted, but the blocks there were rotated in the opposite direction and now slope fifteen to twenty degrees to the west. These opposite slopes suggest the sides of a wide mountain arch raised between the Connecticut and the Hudson River, whose axis was continued southward through the region of the New Jersey coastal plain and offshore waters. But the raising of the arch was accompanied or followed by the fracture and settling which show on its sides. Wherever the Triassic sediments have been preservd in the Appalachians they show this phenomenon of tilting and faulting, indicating a general crustal movement. Each block lifted up would form a ridge or mountain, each block let down would form a trough or basin. Where the principal movement of the blocks was tilting, rather than elevation or subsidence relative to adjacent blocks, the upturned edge of each block would form a ridge with a steep face along the fault plane and a gentle slope following the dip of the strata. The lack of any known sediments deposited in basins from the erosion of the fault blocks suggests that general uplift prevailed over the whole Appalachian province and that the differential movement between the blocks was one of different degrees of uplift; that there was nowhere real downsinking. The greatest erosion was on the two sides of the basins facing each other. From those sides the sediments have been completely removed, which, along with the sloping away of the crust blocks from the central axis, shows that the uplift was between the Connecticut and Hudson valleys. Over this region the only remnant of Triassic sediments preserved lies in the Pomperaug Valley. The least uplift was on the western side of the New Jersey Triassic area and the eastern side of the Connecticut area, for in those marginal belts the greatest depths of Triassic sediments remain. In Connecticut the regional eastward dip shows that the western side of each block was elevated relatively to the eastern side and the difference in the elevation varied with the width of the block. In New Jersey the dip and therefore the relative movement was in the opposite direction.

Yet, in spite of this great crust movement, which could not have been earlier than the beginning of the Jurassic, a peneplain

had been developed by the end of that period. This is shown by the fact that the Potomac deposits of the late Jurassic or early Comanche are laid down on a gently hilly surface which was eroded across the Triassic and all the older rocks. As measured by the work of erosion, Jurassic time, the noon-time of the reign of reptiles, must have been long.

But the larger crust movements are slow, though marked by the spasmodic violence of earthquakes. Erosion begins at the same moment as uplift and its rapidity is increased with the height of the mountain growth. Therefore in reconstructing the regional landscape at the close of the tilting and faulting movement, the upturned sides of the crust blocks must be shown as already partly destroyed, though the mountains still hold through the early Jurassic considerable relation to the tilting character of the movement as well as to the position of the more resistant rocks. The magnitude of the fault movements suggests that some of the block mountains of Connecticut may have even reached the clouds. Some of the uplifted blocks, however, mantled by soft rocks, were rapidly sapped by erosion and could never have attained much of the height suggested by the structure. Other uplifted portions, composed of hard and massive rocks, must have required the whole of Jurassic time for their degradation.[1]

Close of the Triassic Sedimentation, Figure 7. — Still another flight backward in time, and the tilted and faulted structure of the Triassic strata has not yet come to be. The nature of the Triassic sediments and the geographic conditions under which they accumulated, rather than the structure imposed later by crustal forces, now engage our attention. The shales and sandstones below the lowest lava flow show a thickness of 5,000 to 6,500 feet where exposed over the western half of the Central Lowland. A small remnant of the same beds occurs some fifteen miles west of the Central Lowland, existing because protected from erosion as part of a down-sunken crust block within the Western Highland. The thickness of these lower beds, as shown by a boring, is here but 1,200 feet, proving a rapid thinning from east to west. Studies in New Jersey by Kümmel indicate that

[1] The problems connected with Mesozoic erosion and the evidence which bears on some of these conclusions have been more fully discussed by the writer on pages 96-109, Vol. xxxvii, American Journal of Science, 1914.

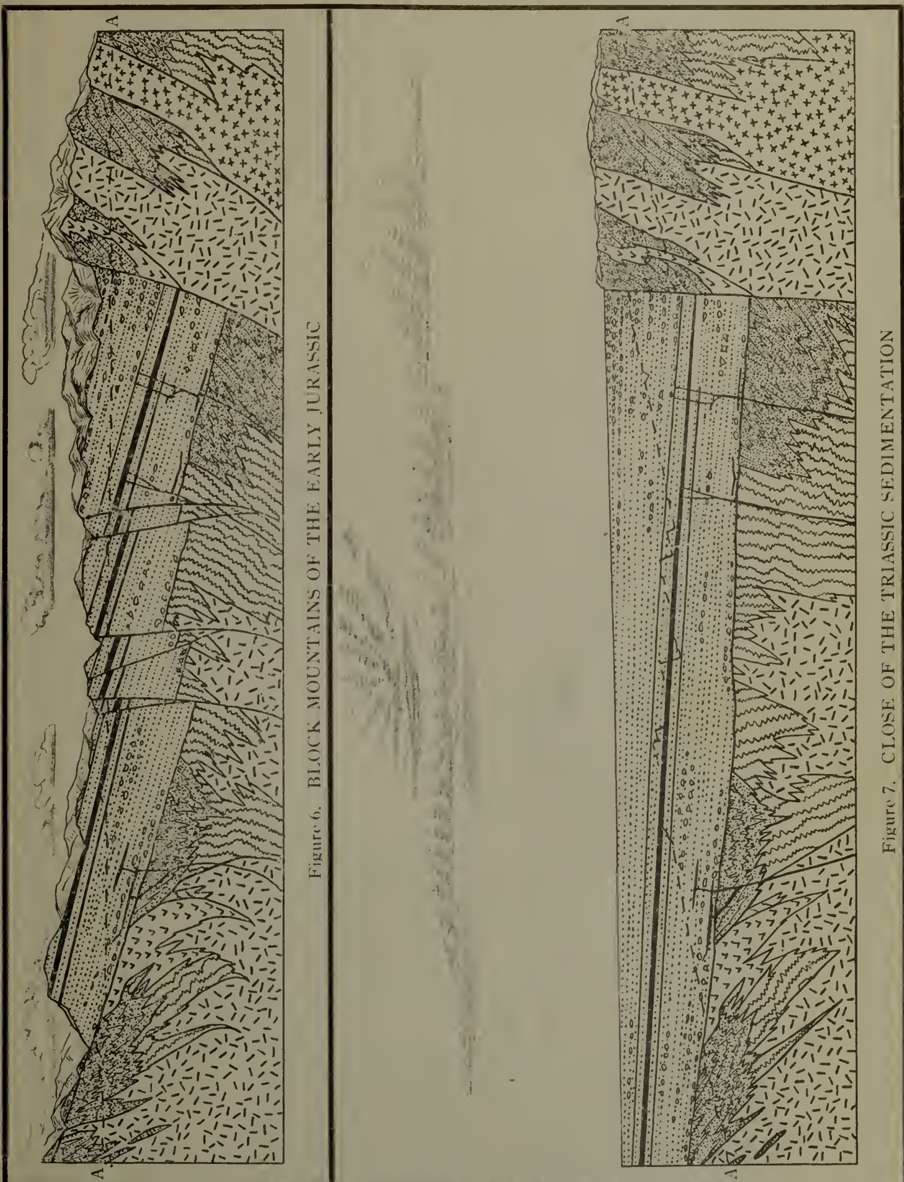


Figure 6. BLOCK MOUNTAINS OF THE EARLY JURASSIC

Figure 7. CLOSE OF THE TRIASSIC SEDIMENTATION

Triassic sediments and lavas.

Paleozoic sediments.

Paleozoic intrusive granite-gneisses.

Pre-Paleozoic complex gneisses.

0. Scale in miles, horizontal and vertical. 10.

A-A Depth reached by later cycles of erosion.

STRUCTURE SECTIONS of CENTRAL CONNECTICUT

there the basal beds disappear toward the north and the sediment was received from both east and west. The muds, sands, and gravels were therefore deposited in basins, the sediments becoming thicker in some places than in others, the floor of the basins spreading as progressive subsidence gave opportunity for deeper sediments.

The strata on the east side of the Lowland show many conglomerate members, indicating a derivation from uplands which lay near-by on the east, though conglomerates are also found near the western border and to some extent in many parts of the deposits. But the dominant segregation of conglomerates near the eastern margin is even more marked in the beds above the lava flows than in those below, and this greater average coarseness of the upper sediments indicates the intermittent re-growth of mountains whose perennial waste kept supplying material for the deposits of the basin. It is necessary to postulate a boundary consisting of a fault wall in order that renewed movements upon it may maintain such a long continued supply of coarse, yet local waste. Similar conglomerates are found also at all levels in the beds which abut against the western margin of the New Jersey area of Triassic rocks. These areas were therefore basins facing each other and bounded on their outer sides by faults, beyond which rose mountain walls analogous to the Sierras which look east and the Wasatch which look west over the desert plains and island mountains of the Great Basin of the West. The eastern limit of the Connecticut Triassic and the western limit of the New Jersey area are still on or near this ancient boundary, but the sediments of the two originally extended toward each other to a greater or less distance beyond their present limits, and the upper beds of the Connecticut area may have been confluent in places with those of New Jersey.

It has been assumed until recent years that practically all sediments came to rest beneath permanent bodies of water, but wider studies of the earth have shown that great depths of sand and mud may be built up in subsiding areas by rivers, as delta and basin deposits. In the Triassic of Connecticut, shrinkage cracks, raindrop impressions, and animal footprints occur abundantly. These marks of subaerial exposure, together with the presence of land fossils and absence of those belonging to salt water, gave rise

(in connection with the assumption, regarded as compulsory, of permanent water bodies coextensive with the sediments) to the hypothesis that the Connecticut Valley in the Triassic was a tidal estuary, in which the ebbing tides permitted the development of the marks of subaerial exposure. But the presence of these marks in most parts of the formation, and not exclusively near the margins of the area, shows rather that the water bodies were migrating rivers or shifting lakes, and that the sediments of river flood plains of great breadth were subjected to periodical drying. The Triassic sediments are therefore best regarded as mainly river deposits of an inland basin, and, if the sea ever gained access during this period, the evidence of it has not as yet been developed.

In these sediments feldspar and mica (muscovite) are abundant constituents, washed in as undecomposed minerals from the hills of crystalline rocks. But the black minerals in these rocks owe their color to iron and part of this is only in a partially oxidized (ferrous) condition. These iron minerals, chiefly hornblende and black mica (biotite), as well as all organic matter, were, in this Triassic climate, with rare exceptions, oxidized and destroyed, the iron oxide (ferric oxide) thus set free giving rise to the dominant red color of the whole formation. Such conditions of partial chemical decay of granitic minerals are found in the basin deposits of semiarid climates, such as those of parts of Spain, New Mexico, and southern California; and it is to such regions that we must turn to find the nearest existing analogues to the climate of Connecticut in the Triassic period.

The marginal conglomerates contain some rounded cobbles of granite and quartzite, showing that they have been rolled by rivers at least some miles. They are rarely, however, more than six or eight inches in diameter and more commonly average two to four inches, though in a few places diameters of one or two feet are found. The rivers therefore were streams of moderate current, not rushing into the basin as mountain torrents. Along with the rolled cobbles and the mud and sand are mixed, however, angular fragments of soft schists and glistening crystals of feldspar, which show by their unworn nature that they have suffered but little transportation and testify to the existence of gravelly wash from near-by hills covered with but scanty vegetation.

The layers of clay left by the flood waters subsiding from the basin floor were dried, cracked, and the edges curled up in drying. The lighter fragments were blown away by wind, but the wind buried other portions of the cracked and curled clay layers beneath drifting sand, and so preserved them in the same curled form in which they dried. While yet soft and unburied, the clay surfaces were often spattered with rain, or received the enigmatical impressions of the varied insect and reptilian life.

Davis in his report on the Triassic rocks of the Connecticut Valley gives estimates of the thickness of each portion of the formation. The sum of his minimum figures is 10,500 feet, the sum of his maximum figures gives 13,100; neither estimate includes the intrusive rocks 500 or 600 feet in thickness. In these estimates, the shales, sandstones, and conglomerates above the uppermost lava flow and constituting the highest part of the formation are estimated as 3,500 feet in thickness, but Davis states that they are possibly much thicker. Following the regional dip and the location of faults as shown by Davis gives, however, on this structure section, a thickness to these upper rocks of between 6,000 and 7,000 feet, but undetected flattenings in the dip or the presence of unmapped faults may reduce this thickness. This section as shown in Figure 1 gives as much as 14,000 feet of strata remaining, and implies possibly as much as 18,000 feet deposited in the region of Middletown. In New Jersey careful measurements by Kümmel gave a total thickness of 20,300 feet, notwithstanding the seeking for evidence which would reduce this large figure. This is even greater than the greatest thickness shown in Connecticut on the present structure section. It is clear then that at least three miles of sediment was deposited in the tracts of greatest subsidence. The basin floors in those places subsided at least three miles during the progress of the period, yet the sediment was sufficiently abundant to keep the basins continuously full of sediment. Slow movements intermittent in nature went forward therefore for a vast period of time, during which erosion planed ever deeper into the folded and metamorphosed rocks of the rising tracts of the Appalachian system, the rock waste being swept into the sinking intermontane basins. Miles of erosion and miles of deposition took place without there

being necessarily alpine heights at any time. Truly, Triassic time was long as measured by its work.

Beginning of the Triassic Sedimentation, Figure 8.— Remove, in imagination, all but the basal layer of the Triassic sediments, and restore the region to the appearance which it presented before the two, three, or more miles of mud, sand, gravel and lava were poured into the sinking basin. A period of erosion just closed, had reduced the previous generation of mountains in this area to isolated hills, and exposed the basal granites and metamorphic rocks. This ancient land surface is still preserved, as Davis has pointed out, as the floor upon which the sediments began to be laid down, and is re-exposed to view on the eastern slopes of the Western Highland by the erosion of the softer Triassic rocks. The straightness and planeness of this tilted floor, where not broken by later transverse faults, indicate that the land had been worn down to a moderate relief before the sediments began to be deposited, showing hills perhaps not more than some hundreds of feet in height. The structure section shows the beginning of the basin as a tendency to downwarp on the one side and upwarp on the other, with the result that the hills are rejuvenated by the uplift and their waste begins to bury the crystalline floor of the basin. But so long as erosion and deposition are more rapid than subsidence no permanent water body can result, as the sediment is more than sufficient to keep the basin filled. It is assumed in the structure section that a differentiation of the subsiding margin of the basin from the rising rim so sharp as to require the development of a fault zone, had not yet arisen, though such a plane of weakness possibly may have been inherited from some earlier time and may have served as a plane of motion at the very initiation of the Triassic basin.

Close of the Appalachian Revolution, Figure 9. — The previous views have been based upon various lines of evidence which give a considerable knowledge of the character of the land surfaces of the periods involved; but, upon leaving behind us the Mesozoic era, all such detailed knowledge fails us. Erosion has removed vast thicknesses of the Paleozoic rocks, and all that remain have been altered and crystallized by heat and mashed by irresistible forces while still buried deep within the earth. Such metamorphic rocks are the exposed foundations of ancient

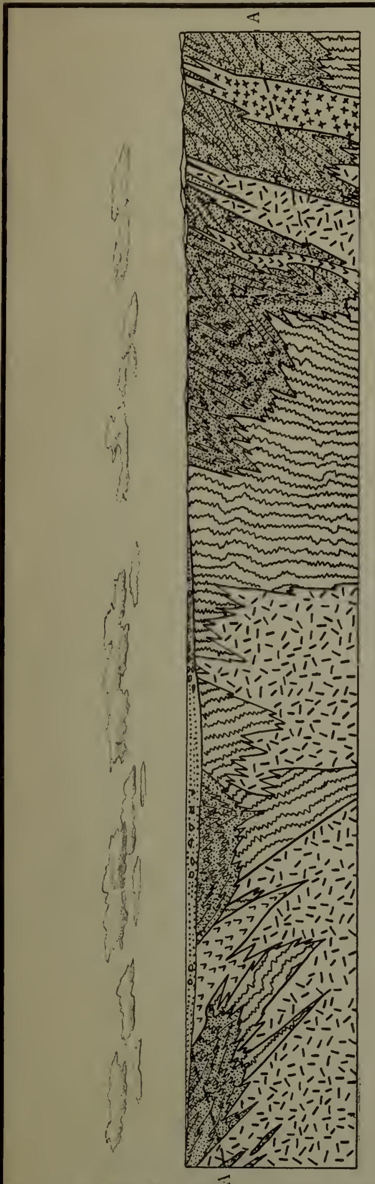


Figure 8. BEGINNING OF THE TRIASSIC SEDIMENTATION

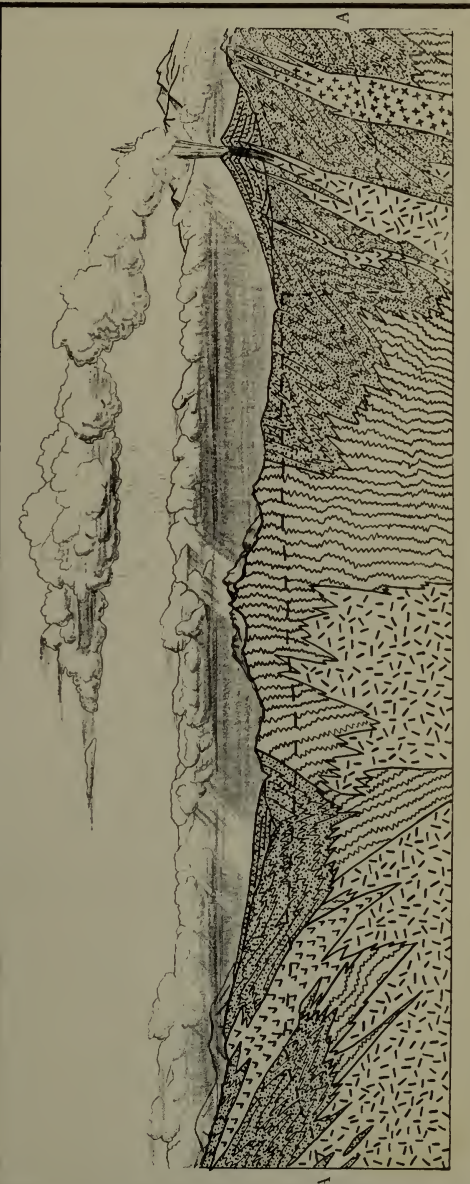


Figure 9. NEW ENGLAND ALPS OF THE LATE PALEOZOIC

Triassic sediments

Late Paleozoic lavas and tuffs.

0. Scale in miles, horizontal and vertical. 10.

Paleozoic intrusive granite-gneiss

Paleozoic sediments.

Pre-Paleozoic complex gneisses.

A-A Depth reached by later cycles of erosion.

STRUCTURE SECTIONS of CENTRAL CONNECTICUT

mountains, but to what extent they were built at the end of the Paleozoic and to what extent in some of its earlier periods is unknown. The fact, however, that the mountains had become removed by the middle of the Triassic period suggests that, although the crustal forces may have been intense during the last movements of the revolution which closed the Paleozoic, the elevation of the regions of subsequent Triassic sedimentation may not have been great. The regions which were later occupied by Triassic rocks may already by the close of the Paleozoic have formed intermontane depressions premonitory of the subsidence of the Triassic. This conservative interpretation has been adopted in the structure section. On the other hand, the forces of erosion have been found capable of removing mountains within the time limits of a single geologic period. A time of unknown duration extended between the Permian folding and the middle Triassic, a time unrecorded by sediments in eastern North America. It is not an unreasonable supposition therefore that in this time-interval mountains of great volume may have been worn away. Certain it is that in eastern New England vast bodies of granite were intruded into the crust in the great revolution which closed the Paleozoic and which is known as *the* Appalachian Revolution. In northern New Jersey also are intrusions which can be proved to be later than the Silurian. Furthermore, much of the metamorphism of western New England is thought by the writer to belong to the late Paleozoic, since post-Ordovician sediments are everywhere altered. Where such great intrusion, folding, and metamorphism are taking place, a mountainous relief is certain to come into existence; but between the mountain ranges may lie intermontane troughs, and it is possible, although no evidence bears upon this conclusion, that central Connecticut may have been such a trough.

There is still to be considered the meaning of the granite-gneisses which penetrate the foundation rocks of the region. These welled up as abyssal molten masses — magmas laden with steam and other gases. They rose from the depths in successive stages: they forced their walls apart, or broke off and swallowed portions of the adjacent rocks, and raised the superincumbent crust into irregular mountain domes. The evidence still shows that sheets of molten rock penetrated into cracks in the over-

lying rock, so that materials of internal and of external origin were mixed in an intricate metamorphic complex.

Probably at certain stages of the igneous activity broad floods of lava, ashes, and coarse fragmental material were poured out, damming and crowding aside the rivers of the time. Volcanoes may have risen in places — cones of igneous materials built over centralized safety-valves. Such surface rocks, if they once existed, have been wholly eroded from Connecticut, though still preserved in eastern New England. In Connecticut they must therefore be restored with a bold hand on the basis of the subterranean evidence now exposed. But over the Lowland even this is hidden by the Triassic rocks, and the structure section shows merely the kind of landscape which may have prevailed in Connecticut at the close of the Paleozoic.

Recently conglomerates of late Paleozoic age which occur near Boston have been found to contain glacial deposits, but it is not probable that the late Paleozoic glaciers of the Appalachians reached an extent comparable to the ice sheets of the last or Quaternary glaciation of North America. The late Paleozoic glaciation of the southern hemisphere, the fragmentary evidence of which is now buried in the solid rocks, was, however, the most widespread known in earth history, and was developed apparently without relation to present climatic zones, occurring in South Africa, India, Australia, and South America. The regional climate in New England at the time is thought therefore to have approached a glacial climate. This cold and humid condition it has been sought to shadow forth in the cloud forms which have been drawn across the landscape.

This final view has penetrated through only the last fraction of geologic time, but already for central Connecticut the vision fails, and, like these lowering clouds, the obscurity of the past hides all which lies beyond.

THE PANORAMA OF GEOLOGIC TIME.

The preceding pages have presented a summary of the evidence upon which the restorations of the successive periods have been based, passing from the present and the known to the past and the unknown. The study has carried us into the close of the Paleozoic. From this turning point in earth history which marks

the fall of night across the long-enduring world of ancient life, let the vision, like a far-traveled bird, take homing flight, and watch while returning to the Age of Man the unrolling of the landscapes which record the flow of time.

In the late Paleozoic the view rests upon the vaguely outlined New England Alps, the result of a profound crustal revolution; one of a series of generations of Appalachian mountains, whose earlier members are even more imperfectly known. The greater heights shine with storm and ice and fire. Earthquake and avalanche and volcanic outbreak speak in deep-voiced tones of the upstriving of mountains. But gray torrents, rushing through gorges far below, sweep along the mountain debris fed to them, and with this burden grind their dark gorges deeper.

At last the upbuilding forces cease and the mountains begin to waste away. The Paleozoic era is left behind, and the Age of Reptiles dawns. The mountains are imperceptibly worn low and a somber vegetation devoid of flowers spreads inward from the plains and valleys. Primitive reptiles and insects follow, to re-people a land which during the reign of alpine mountains had been an almost lifeless waste.

At length a new movement becomes pronounced; down-sinking of long troughs or basins begins, accompanied by the uplift of neighboring areas. The sediments from the uplands are in excess of the amount needed to level up the subsiding areas, with the result that, although in seasons of storm much of the wide expanse is covered with running streams and temporary lakes, in the recurrent times of drought the streams give way to shifting sands, and the lakes shrink, leaving behind them flats of mud which dry and crack. This continued filling up by the loading of those areas starting to sink, accentuates the movement, and causes the greatest sinking to be on the margins of the basin where the greatest amounts of sediments are received. The local intensities of the strains produce breaks in the foundation, and movements take place on the fault planes which on the farther sides sharply bound the basins. Profound earthquakes mark each slip of the crust blocks against each other and attend the repeated rejuvenation of the marginal cliffs. As the observer continues his age-long watch, sediments are seen to gradually extend over the basin floor and blanket the low interior hills which at first

added to the waste. At times when the movements cease, the cliffs wear back, the sediments become fine and may extend somewhat beyond the structural boundaries. At three different intervals great floods of lava well out of fissures, spread far and wide, and temporarily obliterate the life over large portions of the basins.

Now let the flight of time be slackened so that the succeeding flashes of color which mark the change of seasons become distinguishable to the eye, and the work done in the successive seasons may be perceived. From the vantage point of the marginal cliffs the eye looks far through the dry air across an alluvial floor, now shimmering in golden Triassic sunlight, now marbled with moon and cloud. The eye looks far and sees island mountains partly buried within the plains, but distance hides from view the farther basin rim. During the season of heavy rains the loose waste is washed from the upland borders over the alluvial plains and into the basin lakes and playas. An herbaceous vegetation, affording food for a swarm of insect life and for the ruling host of biped reptiles, springs into being with the coming of the rains. Then the skies clear, the waters drain away, and during the following season of dryness the landscape turns brown, save for the evergreen trees and those smaller plants which grow near the scanty permanent waters. The flood plains become dried and cracked, sands blow from the temporary stream channels over the adjacent flats, and the warring horde of reptiles small and great leave abundant bird-like footprints, as, impelled by thirst, they follow the shrinking waters. The following layers of sediment seal for future ages these records of a strange and varied life whose story but for this would have been forever lost, since the alternate drying and wetting of the sediments is a condition which prevents the preservation of the bones.

But, again looking toward the future and once more speeding the flight of time, at last two or three miles of sediments are seen to have accumulated in central Connecticut, and the Triassic period has drawn to a close.

Now, in the early Jurassic, an extensive crust movement is inaugurated, but not as of old by folding or granitic injection and metamorphism due to crushing forces. The progressive subsidence of the basin with elevation of its walls which had marked

the Triassic, changes to a great fracturing of the crust which spreads over Connecticut and along certain belts of the Appalachian system, especially involving the regions of previous movement and deposition. In Connecticut the eastern and western portions suffer relative uplift, and thus the central valley becomes outlined. The individual slices or blocks, many of which are miles in width, are rolled partly over, and their fractured sides slip past each other hundreds or even thousands of feet. The western side of each block is tilted upward, but the eastern side drops down relatively to the block next eastward. The faulting is a progressive readjustment of the broken parts of a broad and gentle arch whose crest lies west of the Triassic basin. Thus there comes into being a new generation of mountains whose higher summits again invade the clouds.

Once more a period of comparative quiet prevails and millions of years pass away. Erosion, working always toward the level of the sea but never below it, planes across the tilted crust blocks, and in southern New England bevels all alike, be they of softer sandstones ribbed with harder trap, or of resistant metamorphic rocks. The mountains once again vanish from central Connecticut, leaving hills a few hundred feet in height as the only surviving remnants, and Jurassic time draws in turn to its close.

But nature never repeats herself, and the crust movements which break earth history into periods are varied through the course of ages. During the Paleozoic the chief lines of uplift had been through New England, and to the south where in later geologic times are coastal plain and sea. Now at the close of the Jurassic the new relation of the Applachians begins to be established. A warping of the crust begins, but the axis of greatest uplift is now farther inland, where, during most of the Paleozoic, subsidence and sedimentation had been the prevailing rule. Toward the margin of the continent, where formerly the Appalachians had risen to maximum heights, subsidence becomes manifest. The sea seeks to advance inland, but the great volume of river sediments from the regions of rising crust holds back the strand-line and builds a wide stretch of delta land. Branching, shifting rivers, spreading into swamps, weave an interlacing tangle of waters through the low alluvial plains. Farther inland is a belt of subdued but yet hilly country. Connecticut is divided between

these two regions, the delta plain occupying more or less of southeastern Connecticut, with a zone of low hills stretching west and north, to rise into mountains in Massachusetts and New York. The whole is green with tropic jungle in which becomes established the first known flora marked by the presence of the higher flowering plants (angiosperms). These flowering plants of modern type for the first time give to the landscape a familiar aspect, and add by their presence to the beauty of the world; but their greater service to the earth's progress lies in that they yield for food their foliage and their fruits. Yet the Dinosaurs by power and ferocity still rule the earth, and more or less aquatic forms of these and other reptiles leave their bones as fossils, mired in the clays of swamps or buried in the silts of rivers.

The eye now notes a change. The streams flow from the hills with gentler current, the hill slopes become less steep, their summits sinking lower. Waste is swept less rapidly out over the delta plain. The ocean strand advances inland across the delta lands. The Cretaceous period has begun, marked by rising and invading ocean waters, which by the middle of this age have flooded the continents more widely than at any time since the ages of the distant Paleozoic. Along the Atlantic shore slight vertical movements of land or sea cause the white line of strand to shift widely, but at the farthest advance of sea the shore lies to the northwest and no land is visible from our view point in central Connecticut. The last traces of the mountains of the past have vanished and the uplands of the future are still concealed. Over the land to the west there still continues, however, the work of erosion. The mountains retreat to those last strongholds, the regions of harder rocks between the distant headwaters of the streams. A peneplain develops and spreads its low and forested expanse far and wide over eastern North America, penetrating between the residual mountain groups, and extending from the Atlantic shores to the shores of that spreading inland sea which joins the waters of the Gulf of Mexico with the waters of the Arctic Ocean.

But the age-long tide turns and retreats at last. In central Connecticut the green of waving forests again replaces the blue of the restless ocean waters. Finally begin the great crust movements which close the reign of reptiles and usher in the Age of

Mammals. In the west the present ranges of the Rocky Mountains become outlined, but in the Appalachian region a broad warping independent of structure raises the old peneplain into a plateau above which rise the few remaining mountains. The movement of uplift is intermittent, and at several times during the Tertiary the sea returns over southern Connecticut and probably reaches as far as the line of our geologic section. Following each retreat of the sea, the rivers flow in southeasterly courses across the bared sea floors. From these channels gained in the last emergence the Connecticut and Housatonic have never been deflected. At each halt in the oscillatory uplift of the land the rivers establish a new base-level of erosion and begin to widen out the valleys in the softer rocks. At last a halt in the latest Tertiary permits the soft rocks of the Central Lowland to be widely eroded to near the level of the sea, while in the same period of time narrow valleys only are cut in the harder rocks of the Highlands.

Now begin those broad oscillations of the continents connected with the crustal and climatic revolution which closes the Tertiary and marks the beginning of the Quaternary period. The movement is dominantly one of uplift, and the rivers cut their valleys deeper in obedience to the law that they shall seek the level of the sea, but even in the softer rocks the new work of erosion is hardly begun when it is interrupted by the coming of the Glacial catastrophe. The winter snowfall begins to exceed the summer melting. Slowly gathering ice fields form, deepen, and creep toward the south, driving all life before the advance of the frozen desert. Warmer intervals come, marked by the retreat of the ice, but the glacier each time recovers its lost ground and advances farther into more temperate latitudes until it reaches to Long Island, and the Allegheny, Ohio, and Missouri Rivers. The northern half of the continent is given over to a reign of ice. The ice margin advances and recedes, and upon each retreat leaves behind it belts of moraines, soil mantles of stony till, rock ledges polished and scored. The elephant and mastodon and others of the race of mammals — warm blooded, clothed with hair, and adaptable to changing conditions — follow quickly northward each recession of the ice.

The ice draws back again, pausing in arctic latitudes. But this time there soon appears from the west a race of savage men. The Human Period has dawned in America. Then like a flash in the swift flight of years another race is seen, pouring in ships across the eastern sea. The genii of nature bow as slaves and at their command there rises from earth the apparition of the cities of civilized men.

In this brief time since the ice fields have retreated and man has mastered the earth, no noteworthy terrestrial changes have taken place. Not even the Glacial soil left by the last retreat of the ice has been washed away. The post-Glacial period may be ten times the length of recorded human history, yet, compared with the work of the preceding ages, it is seen to shrink to nothing in the scale of geologic time.

THE MEANING OF THE SHIFTING SCENES.

There comes to us from ancient times the myth of the Titans and their wars against the powers of heaven. They were the twelve lawless giant children of Uranus — the lord of heaven and ruler of earth —and of Gæa — the personification of earth, the primal mother and first-born of Chaos. Because of the menace of their growing strength they were imprisoned by their father in Tartarus, but from these abysses of darkness they were released by their mother, incensed at the fate of her children. They piled mountains on mountains till they climbed to heaven. In wild battle they overthrew and abased their father; and Cronus the youngest of the Titans, sat upon the throne. But the curse of Uranus against his sons was fulfilled. The reign of Cronus came to an end, overthrown in turn by his own son Zeus. He was then compelled to disgorge the children which he had swallowed in vain effort to thwart his father's curse. The rebellious Titans were again imprisoned; guards were set to watch them forever, and the gods of sun and sea and rain, the children of the Titans, ruled in their stead.

Into this ancient myth we, in this latter day, may read more than the early narrators of it knew. Previous to the age of science, the earth was looked upon as changeless since the first creative day. But geology, by interpreting the meaning of ceaselessly moving air and water, and by studying the record of the

crust, has opened to the mental vision the warfare of the resistless powers which shape and reshape the surface of the world.

Solar heat maintains the earth's water largely in fluid, and the atmosphere in gaseous, form. But the concentration of solar energy upon certain parts of the earth produces circulation systems in these mobile envelopes which work to spread out this energy and lead to its dissipation. The air, most easily moved by changes of temperature, carries with it from the ocean the vapor of water, to be condensed in cloud and precipitated in rain, and thus extends the beneficent water circulation over the surface of the lands. The air sweeps along desert dust and sand; the flowing waters carry away rock detritus and hold also rock substance in solution. The exposed portions of the crust are thus impelled to sluggish changes, recorded through geologic time by erosion and deposition. Movements in the four Greek elements — fire, air, water, and earth — form a mutually dependent chain. These elements become interwoven and the energy which flows through them from sun to earth drags all into circulation. These surface energies of the world are sun-born forces, working to level the uplifted lands and extend the dominion of the sea, and their control of the earth's surface is recorded by the sediments piled up through geologic time.

The earth, however, possesses forces of her own. From time to time the eroded lands rise again. More locally new mountain ranges are reared above the clouds, and re-invade the home of Zeus. The crust of the ocean sinks lower, draws from the lands the flooding waters, and restricts the rule of Poseidon to his proper realm. The energies of the mysterious interior overflow, and lava fields or volcanic cones add to the rocky crust above the level of the sea. Thus the earth-born Titans chafe against their subjugation. They are never completely conquered; and here and there for a brief space of time their rebellion, as they again claim dominion, spreads ruin on the earth.

But there are disgorged from the molten rocks, which break into or through the outer crust, great quantities of water vapor and carbon gases with smaller quantities of other gases. Freed from the pressure of the depths the gases expand to many times the volume of the parent rocks. Judged by the amount of the igneous rocks which have invaded the outer crust through geo-

logic time, the emanations seem possibly sufficient to have given rise to the entire atmosphere and ocean without necessarily invoking a primal or cosmic source. But the enrichment of the atmosphere gives the rain increased power to destroy the rocks. The ocean probably has increased in volume through the ages, fed by steam exhaled from the underworld, and has thereby gained in power to invade the rain-eroded lands. This result, however, has been counteracted by a more than corresponding increase in the volume of the ocean basins. So it is seen that the upward struggles of the inner earth, by increasing the air and water at the surface, have added in the end to the power of the opposing agents and insured the more speedy ruin of those structures which the earth-born forces build.

Thus the surface of the earth is the battle ground of forces born of the sun and working through the earth's gaseous and liquid mantles against those other forces born of the earth's interior which mold the crust with giant power. Geologic history is the record of this never-ending and ever-shifting warfare between the powers of light and the powers of darkness. Progress is born of conflict not only in the human world, but in the material world as well.

A review of the geologic record carries us back to the tangled rocks of the Archeozoic, and gives knowledge of an æon when the Titans of the inner earth burst their bonds. Mountains spread across the continents and reached above the clouds. Igneous activity seems to have been for a time dominant in the outer crust of the earth. The older structures were destroyed and world-wide metamorphism of the rocks prevailed. Great masses of older sediments, now profoundly mashed and crystallized, show that the early Archeozoic does not record the beginning of the earth, but that a still earlier rule of the external forces was overthrown. The reign of Uranus had come to an end and Cronus sat upon the throne. For a period the earth-born Titans held their riotous sway, but their power decayed, while that of the children of Cronus increased, until in the sediments of the Lower Huronian is shown an establishment of the orderly processes of the external world. But again the Titans rose in their might, and once more over wide continents they shattered the crust and raised high mountain domes; yet in so doing they spent their

strength. The cloud-dwelling god of thunder and rain was never conquered, but bided his time, and, slowly tearing down the structures built by the Titans, brought to an end the Archean. The dominance of Zeus and Poseidon, the gods of the outer world, was now established for all time: the reign of the Titans was ended, and that orderly sequence of the strata was begun which records the history of the earth and the life that dwells thereon.

Still, the re-imprisoned Titans are seen from age to age to bend and break and lift their prison roof, seeking to raise themselves anew in defiance of the lords of rain and sea. But never, since the world-wide misrule marked by the Archean rocks, have they mastered the surface of the earth. The igneous rocks which are poured out are soon buried or swept away, and the mountains which are raised again toward heaven are fleeting features on the surface of the ancient earth.

But it is only because of this eternal conflict that all life of the land has found existence. The currents of air and water tend to make equable the climates of the zones, and, as rain, the water sustains the life of the lands. Air and water break down the rocks into soil, the life-nourishing mantle of Earth. As it becomes impoverished of soluble matters, it is with equal pace worn away from above and rejuvenated from the rocks below. The forces of uplift and of igneous activity widen the land areas and renew their elevations. The escaping gases enrich the atmosphere with carbon dioxide and thus provide the gaseous food of plants. Let the sun-born forces resign their rule, and a speedy death would sweep over the surface of the world. Let the fettered Titans cease their striving, and in a few short geologic ages the wasted lands would be invaded by the sea. The water would have widened like the air into a universal envelope; at last would be stilled through nature the reverberations of the ever-sounding sea, and Poseidon, another child of Cronus, would come to share with Zeus supreme dominion of the world.

Land life, as shown, only finds existence because of the world conflict, and in its midst. But beyond mere existence there has prevailed that law of progress which has built up flower, beast, bird, and man from the same primal germ. This law too rests upon the same eternal struggle, because life tends always to be-

come adjusted to its surroundings. That which does not change becomes extinct, and the world is inherited by the changed and best adapted. No sooner, however, has adjustment come in a time of geologic quiet than an epoch of earth unrest starts again the turning wheel of change. New migrations begin, and new conflicts arise between the forces of earth and her living forms: only the best of each kind is spared to carry forward the web of life. Thus it is that the changing environments resulting from the shifting vicissitudes of the battle between the forces of earth and sun, as marked by the advancing and retreating strand-lines, and the fall and rise of mountains, have made for progress, and have stimulated the evolution of all that higher life which dwells upon the lands, and of that highest life which has begun to look with understanding into the depths of space and time.

In the shifting scenes which have been followed are shown, graphically expressed for one locality, this warfare whose comprehension is a key to the history of the earth.